

# *A geologic time scale 1989*

W. Brian HARLAND

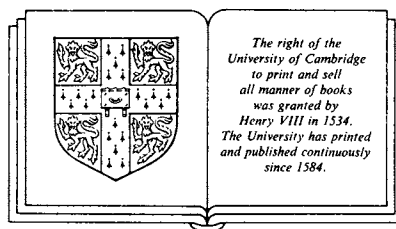
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## 1

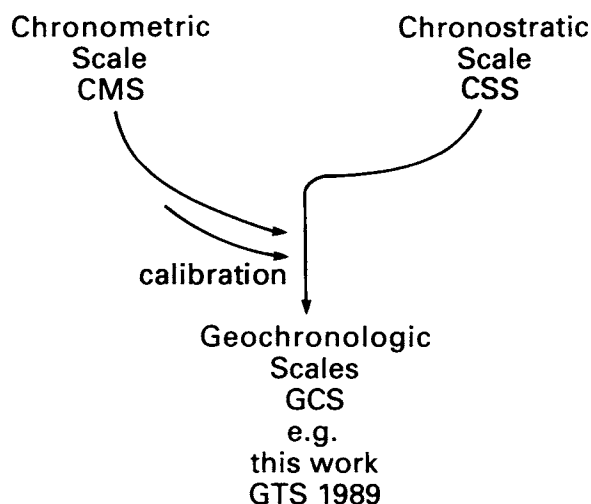
## Introduction

- 1.1 Objective
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- 1.7 Local rock units
- 1.8 Geochronologic scales (GCS)
- 1.9 Procedures adopted in the construction of this time scale (GTS 89)

## 1.1 Objective

A geologic time scale (geochronologic scale) is composed of standard stratigraphic divisions based on rock sequences and calibrated in years. It is thus (Figure 1.1) the joining of two different kinds of scale, a chronometric scale and a chronostratic scale. A chronometric scale (CMS) is based on units of duration – the standard second – hence a year. A chronostratic scale (CSS) is now conceived as a scale of rock sequences with standardized reference points selected in subsections, each particularly complete at and near the boundary and known as a boundary stratotype. The chronostratic scale is a convention to be agreed rather than

Figure 1.1. The making of a time scale.



discovered, while its calibration in years is a matter for discovery or estimation rather than agreement. Whereas the chronostratic scale once agreed should generally stand unchanged, its evaluation will be subject to repeated revision. For this reason, no geologic time scale can be final and this particular attempt (GTS 89) must be qualified by '1989', its year of completion.

The concepts employed here have in the past been used in different combinations of words, for example **(standard) (global) (geo)chronostrat(igraphic) (time) scale** is generally contracted to **chronostratic scale**. Other contractions may be clear enough in context. Such acronyms are shown in Figures 1.1, 1.2 and 1.4 and explained on p.xvi.

Regional chronostratic scales (RCSS) have gradually given rise (Figure 1.2) to the single global traditional stratigraphic scale (TCSS). This is being refined and standardized at global stratotype sections and points (GSSP) to give definition to the standard global chronostratic scale (GCSS); see Chapter 3. Regional points are competing for GSSP in this process. Chronometric scales were also first developed regionally and are being standardized as a single agreed standard chronometric scale (GCMS); see Chapter 2.

The calibration of any chronostratic scale in years yields what is commonly called a time scale (e.g. the title of this book, GTS). To distinguish such a calibration from other time scales they may be referred to generally as geochronologic (chronostratic & chronometric) scales (GCS).

Figure 1.2 shows the relationship of these entities.

**Figure 1.2. Steps in the development of a time scale – GSSP = Global stratotype section and point; CMS = Chronometric scale; CSS = Chronostratic scale; GCS = Geochronologic scale; GCMS = Global chronometric scale; GCSS = Global chronostratic scale; TCSS = Traditional chronostratic scale; RCMS = Regional chronometric scale; RCSS = Regional chronostratic scale.**

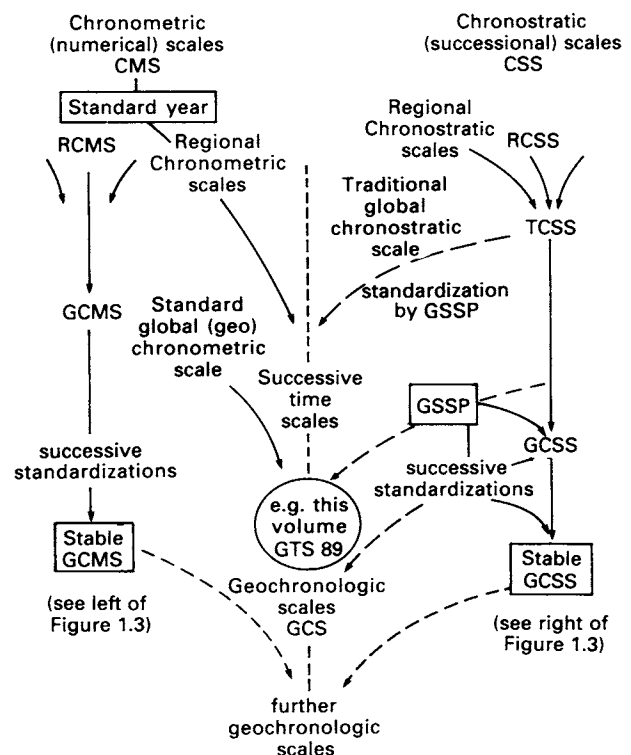


Figure 1.3. Outline chronometric and chronostratic time scales.

| Ga  | Chronometric    |             | Chronostratic                 |  |
|-----|-----------------|-------------|-------------------------------|--|
|     | Eon             |             | Era                           |  |
| 0   |                 |             | Cenozoic                      |  |
|     |                 |             | Mesozoic                      |  |
|     |                 |             | Paleozoic                     |  |
|     | Phanerozoic     |             | Sinian                        |  |
| 1.0 |                 |             | Riphean                       |  |
|     | Pt <sub>3</sub> | Proterozoic |                               |  |
|     | Pt <sub>2</sub> |             |                               |  |
| 2.0 | Pt <sub>1</sub> |             | Animikean                     |  |
|     |                 | Archean     | Huronian                      |  |
|     |                 |             | Randian                       |  |
| 2.5 | Ar <sub>3</sub> |             |                               |  |
| 3.0 | Ar <sub>2</sub> | Archean     | Swazian                       |  |
|     | Ar <sub>1</sub> |             | Isuan                         |  |
| 4.0 |                 | Priscoan    | Hadean                        |  |
| 5.0 |                 |             | Origin of Earth<br>pre-Hadean |  |

Figure 1.3 as an example illustrates side-by-side the evolving state of two such scales. Figure 1.4 identifies the logical steps in this process of calibrating sequences of natural events or natural chronologies (NCS).

## 1.2 The traditional chronostratic scale (TCSS)

The prodigious stratigraphic labours of the nineteenth century resulted in innumerable competing stratigraphic schemes. To impose some order the first International Geological Congress (IGC) in Paris in 1878 set as its objective the production of a standard stratigraphic scale. Suggestions were made for standard colours (Anon. 1882, pp.70–82), uniformity of geologic nomenclature (pp.82–4) and the adoption of uniform subdivisions (pp.85–7). There was also a review of several regional stratigraphic problems. In the

succeeding congress at Bologna in 1881, many of the above suggestions were taken substantially further, i.e. international maps were planned with standard colours for stratigraphic periods and rock types (e.g. Anon. 1882, pp.297–411) and annexes contained national contributions towards standardization of stratigraphic classification, etc. (pp.429–658).

In spite of this promising start, the IGCs did not have the continuing organization to carry these proposals through, except for the commissions set up to produce international maps. It was not until the establishment of the International Union of Geological Sciences (IUGS) around 1960 that the promise had a means of fulfilment, through the IUGS's Commission of Stratigraphy and its many subcommissions.

By 1878 the early belief that the stratigraphic systems and other divisions being described in any one place were natural chapters of Earth history was fading and the need to agree some conventions was widely recognized. Even so, the practice continued of describing stratal divisions largely as biostratigraphic units, and even today it is an article of faith for many that divisions of the developing international stratigraphic scale are defined by the fossil content of the rocks. To follow this through, however, leads to difficulties: boundaries may change with new fossil discoveries; boundaries defined by particular fossils will tend to be diachronous; there will be disagreement as to which taxa shall be definitive. So the traditional stratigraphic scale is of necessity evolving into a new kind of standard chronostratic scale.

## 1.3 Standardization of the global chronostratic scale (GCSS)

At the 1948 IGC one of the first attempts to standardize a stratigraphic boundary was made (the Pliocene–Pleistocene boundary by convention at the base of the Calabrian Stage in

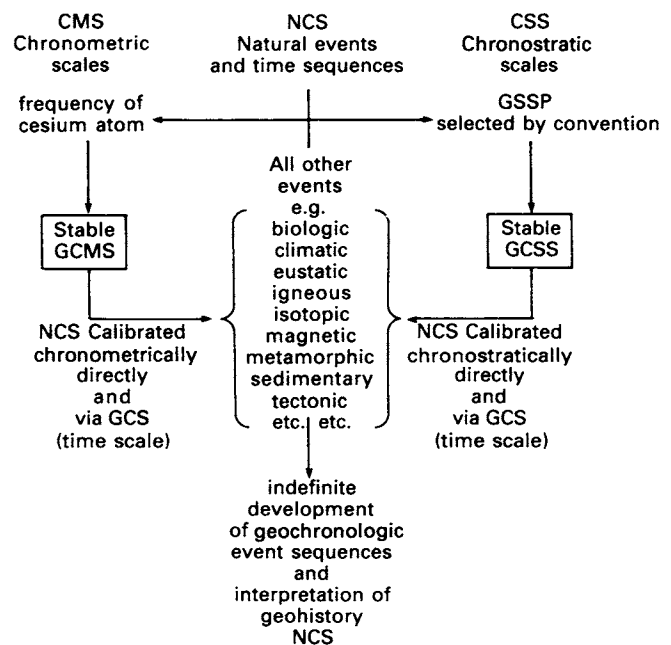


Figure 1.4. Steps in the calibration of sequences of natural events.

Italy). Such a decision had to be an agreed convention. It was agreed to standardize divisions at their boundaries only, and each boundary at only one locality. The international procedure to standardize such a boundary at a single point in a reference subsection was worked out by the Silurian–Devonian Boundary Working Group. Their procedure was first to agree upon the approximate position in the biostratigraphic sequence that would best fit existing usage and then to find a succession somewhere in the world where the Silurian–Devonian boundary was represented in fossiliferous rock with the best potential for correlation. If we take this procedure as a guide, the requirements for the standard **geo- or global chronostratic scale** (GCSS) follow.

A sequence of reference points in continuous subsections of uniform (marine) sedimentary facies selected with suitable potential for international correlation, state of preservation and access needs to be agreed. The precise reference point for each boundary is now known as the **global stratotype section and point** = GSSP (Cowie *et al.* 1986). It is then conceived as representing the point in time when that part of the rock was formed. Rock immediately below (formed before the point in time) or above (formed after it) should contain characters for correlation. Pairs of such points then define the intervening time span. The global chronostratic scale is ultimately defined by a sequence of GSSP.

The procedure has a significant consequence in the conception of chronostratic divisions. Before the standardization just described, the intervals were conceived as being the time equivalent of a rock unit that was already defined. Thus systems (series, stages or chronozones) were first described and the geologic periods (epochs, ages, chrons) were derived as the corresponding time intervals. The practice implied the assumption that the bases of such rock divisions are not diachronous. Even without that assumption, for a while ‘body stratotypes’ (type sections) were thought to be sufficient. The new procedure of defining boundary points effectively reverses the derivation. The time division (period, etc.) is now defined precisely by selecting initial and terminal points, while the corresponding rock formed in the interval (system, etc.) cannot be identified with certainty at its boundaries other than at the GSSP depending, as it does, on estimates of relative age by correlation. This generally yields a chronostratically well-dated main body of the rock division, but with uncertain initial and terminal boundaries away from the GSSP. To emphasize the primacy of time in such a time scale, Early, Mid and Late are used rather than Lower, Middle and Upper, for subdivisions of the primary named intervals.

Various names have been proposed for the newly standardized scale. The Geological Society of London (GSL) used **standard stratigraphic scale** (SSS), in contrast to the traditional stratigraphic scale (TSS) and regional stratigraphic scales (RSS) out of which it was evolving (George *et al.* 1967). The International Subcommission on Stratigraphic Classification (ISSC) referred to it as the **standard global chronostratigraphic scale** in the *International Stratigraphic Guide* (Hedberg 1976). Both the American Stratigraphic Code, and the ISSC *Guide* into which it grew, confused the matter somewhat. They divided the standard scale as

described here into two categories: periods and systems. Their **geochronologic units** refer to periods, etc. and **chronostratigraphic units** to systems, etc. It is obvious that time and rock are different (e.g. as indicated by the words period and system), but when defined they both derive from the same standard reference points. The two apparently distinct disciplines, geochronology and chronostratigraphy in Hedberg’s terminology, are thus different aspects of a single procedure.

It is both traditional and convenient to use a hierarchy of names for stratigraphic intervals (era, period, epoch, age, chron). The use of the hierarchy is largely a matter of habit but it has its uses in both economy of description and in describing events of different duration or uncertainty of correlation. The chronostratic divisions of any rank in the hierarchy are defined in the same way by GSSP. There is no difference in principle between a GSSP defining an initial chron or an initial era boundary. Indeed, the same GSSP may serve as the initial boundary for several ranks in the hierarchy. The ranks are then conterminous and the principle of conterminosity simplifies the use of a hierarchy.

The names for the spans are generally those favoured from classic sections. Once selected for the GCSS, however, they cease to have local reference and must be used internationally for the time span defined by the limiting points. It is convenient to retain familiar names but, when redefined at some distance from the eponymous locality, the local geologists must accept that the name has acquired a new meaning and possibly avoid its old use by renaming the original rock unit. For example, when Pridoli was accepted as an epoch name in the GCSS the original Pridoli Formation from which it came was renamed.

The above principles developed for the global chronostratic scale can be applied to regional chronostratic scales (RCSS) as a step in the process of correlation, but the multiplication of scales is not generally helpful. The work of standardization is considerable and need not be multiplied. Until such a global time scale is standardized, points in regional scales (RSSP) may be regarded as candidates for GSSP. The development of the global chronostratic scale is addressed further in Chapter 3.

#### 1.4 The global chronometric or geochronometric scale (GCMS)

The proposal for a global chronometric scale is quite different. The scale is linear, i.e. it is compounded of units of equal duration. Therefore all that is essential is to define a standard unit – a second of time based on the cesium ‘clock’ – and so derive one year. In the same way that a linear scale of length is constructed from unit lengths and is so defined, the chronometric scale exists by virtue of the definition of a unit of duration (see Chapter 2).

A further convention is to compound the units into longer, named intervals. Such a scheme of millennia ( $10^3$  yr), gigennia ( $10^9$  yr), etc. is by no means essential but, as with the higher ranks of the chronostratic hierarchy, they may be convenient in general expressions of age. Unlike the chronostratic divisions they will be defined not by reference points in rock but by initial and terminal points, each defined

by a finite number of units of duration BP (Before Present – by convention in  $^{14}\text{C}$  determinations counted from 1950). These matters are taken further in Chapter 2.

There are those who think that there is some advantage in treating Precambrian history as sufficiently different from Phanerozoic history as to require the use only of named chronometric divisions for Precambrian time. This opinion derived from the general absence of fossils as it seemed in the Precambrian rocks, which is no longer so. Thus the Subcommission on Precambrian Stratigraphy of the IUGS agreed in 1976 that the boundary between Archean and Proterozoic should be defined at 2500 Ma exactly (but not yet ratified by the International Commission of Stratigraphy (ICS)); moreover, other subdivisions of Precambrian time have also been proposed along the same lines, as will be seen in Chapter 2. Our preferred alternative would be to extend the scheme of named chronostratic divisions backwards into Precambrian time (as is developed in Chapter 3). A parallel development of named chronometric divisions forward through Phanerozoic time is not proposed here but cannot be dismissed.

There is thus only one standard for a general chronometric scale (the second and hence the year). For the geochronometric scale **present** needs to be defined and the difference between BP and BC is generally irrelevant. The matter at issue is the naming of spans of time and their numerical definitions. Together these should provide a stable GCMS (see Chapter 2).

## 1.5 Statement of age

The two conventional scales outlined above (chronostratic and chronometric) do not in themselves enable us to date or to time-correlate rocks one with another. Their function is to provide agreed standards for expressing the ages of rocks. They reduce the number of ways in which geologic ages are stated (ideally to two: one by named intervals between defined events (GSSP) and one numerical). Both are conventions and neither is better than the other. The two do not and cannot define each other and so they are both needed. According to circumstances, some rocks can be dated chronometrically more precisely than chronostratically and for others more precise ages can be given chronostratically. Only if the conversion of one scale to the other were far more precise than it now is could any age usefully be given either in years or in named chrons.

Both scales are decided by convention and have therefore been referred to as artificial; but the word artificial has an unfortunate connotation of inferiority. The scales are artifacts and artifactual would better express their conventional nature.

Alternative terminology for the two ways of stating age (chronometric and chronostratic) have been **relative** and **absolute**, which is an unfortunate distinction because both are relative and neither is absolute. In German, **Phanomologische Alter** and **Chronometrische Alter** have been used (Englehardt & Zimmermann 1982, p.114). **Stratigraphic** is also unsuitable for CSS because in the wider sense of stratigraphy as geo-history both expressions for age are stratigraphic.

There is some similarity between the above pairs and

McTaggart's (1908) **A series** and **B series**. These two concepts (argued by philosophers rather than geoscientists) have been applied to human experience of ever changing past, present and future (A series). This gives an objective sequence of events (whether conscious or historical) which relate to other events being earlier, coeval or later. Such events may be consolidated in a chronometrically calibrated sequence (B series, i.e. the **real time** of Mellor 1981).

## 1.6 Natural chronologies (NCS) and event sequences

Particular historical geological phenomena are commonly known as events. They are of many kinds, for example magmatic, sedimentary, biologic, tectonic, magnetic, eustatic, climatic, celestial and geochemical. They are the basis of stratigraphy in the full sense of geohistory and especially of event sequences with time-correlation. The current term **event stratigraphy** is redundant because stratigraphy has always depended on interpretation of strata in terms of events. Some events are more obvious, identifiable, widespread, predictable, or sudden than others. All are the subjects of investigation. Therefore all are in part matters of opinion – the substance of hypotheses liable to revision.

Interest in these natural phenomena motivates science. The time scales already discussed are tools only for the study of phenomena. The scales have no application without time-correlation, which is entirely dependent on the interpretation of natural phenomena. Events are such interpretations.

A GSSP may be conceived as relating to phenomena and therefore to interpreted events. For example, the tip of the 'golden spike' (the colloquial term for a GSSP) may separate two sand grains, one deposited before and the other after the designated point in time. In a uniform sequence the point has little significance as a special event – it is almost a non-event and so it can be the more readily agreed as a point in the conventional chronostratic scale.

Other events – a particular astronomical year – or (later) the perturbations of the cesium atom have been selected as the basis of the chronometric scale.

The distinction between time scale as a tool for the study of natural history and something expressing natural history itself has only slowly become recognized. It was previously assumed that most classes and subclasses of event would somehow fit into the divisions of the story that was gradually being revealed. Calibration of event sequences against independent time scales liberates the phenomena for investigation of their interplay. Some examples of classes of event sequence follow.

**Sedimentation or magmatism** (with subsequent alteration) yields bodies of rock that provide the most convenient descriptive units (formations) as introduced in Section 1.7.

**Biologic** evolutionary history, especially for Phanerozoic time, has given us not only the principal means of time-correlation but the basis of the unique progressive traditional stratigraphic scale. Definition of biozones, through biochrons, to chrons defined by GSSP, is only now slowly taking place. For this reason the figures in Chapter 3 list selected biostratigraphic events. In due course the distinction